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Baccalauréat International
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PHYSICS
HIGHER LEVEL
PAPER 3

Wednesday 5 November 2008 (morning)

1 hour 15 minutes

Candidate session number

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INSTRUCTIONS TO CANDIDATES

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Answer all of the questions from two of the Options in the spaces provided.
- At the end of the examination, indicate the letters of the Options answered in the candidate box on your cover sheet.

Option D — Biomedical Physics

D1. This question is about scaling.

Two mammals, X and Y, have similar body shapes. The mass of mammal X is 40 kg, whereas the mass of mammal Y is 10 kg.

(a) (i) Deduce that the ratio

$$\frac{\text{length of mammal X}}{\text{length of mammal Y}}$$

has a value of 1.6. *[2]*

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(ii) State **one** assumption made in the calculation in (a)(i). *[1]*

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(b) Mammal X and mammal Y are both exposed to a very cold environment. Explain why the body temperature of mammal X would fall more slowly than that of mammal Y. *[3]*

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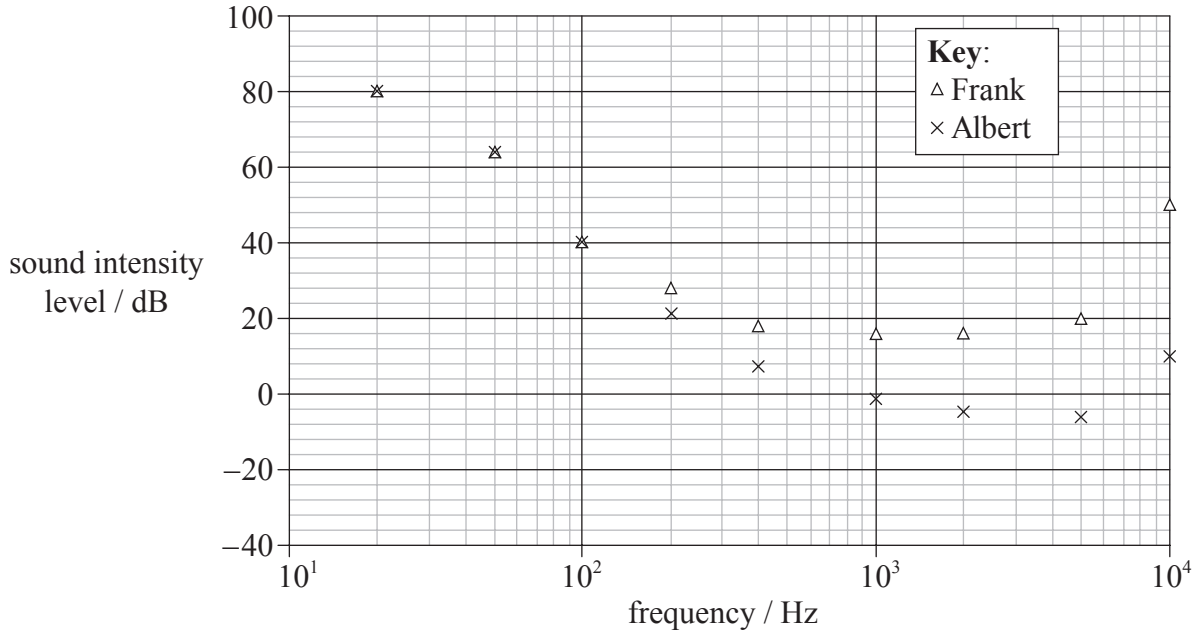
D2. This question is about hearing.

The graph below shows the variation with frequency of the threshold of hearing for two identical twin brothers, Frank and Albert.



Frank and Albert have worked in different places for many years. One workplace was very quiet and the other was very noisy.

(a) Suggest, with reference to the graph, which brother is likely to have worked in the noisy workplace. *[2]*

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(b) For a frequency of 10 000 Hz, calculate the ratio

$$\frac{\text{intensity of the sound just detectable by Frank}}{\text{intensity of the sound just detectable by Albert}}.$$ *[2]*

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(This question continues on the following page)

(Question D2 continued)

(c) State **one** feature of the graph that suggests one of the brothers suffers from sensory hearing loss. *[1]*

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(d) A person with a damaged cochlea will have loss of hearing at selected narrow frequency ranges. Explain how this phenomenon leads to a loss of speech discrimination. *[3]*

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D3. This question is about X-ray imaging.

(a) Outline how a CT (Computed Tomography) X-ray image is produced and state the nature of the image. *[3]*

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(b) Describe the use of barium in X-ray imaging. *[3]*

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D4. This question is about the conversion and expenditure of energy by humans.

(a) Explain what is meant by basal metabolic rate. *[2]*

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(b) Suggest why the basal metabolic rate for a teenager is likely to be higher than that for an adult of the same mass. *[1]*

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(c) Two adults, Suki and Ann have the same mass. Suki is sitting in the shade indoors in a room maintained at 20 °C, whereas Ann is sitting in direct sunlight where the average temperature is 32 °C. Evaporation and expiration are two processes that help temperature regulation in the body. Discuss the relative importance of these two processes for Suki and Ann.

(i) Evaporation: *[2]*

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(ii) Expiration: *[1]*

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D5. This question is about physical and biological half-lives.

A patient is injected with a radioisotope. The physical half-life of the radioisotope is 10 days and its biological half-life is 15 days. Calculate the fraction that remains in the patient after 30 days. *[4]*

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Option E — The History and Development of Physics

E1. This question is about the motion of stars and planets.

Three observations that can be made concerning the apparent relative motion of planets and stars are:

- stars do not move relative to each other
- planets move relative to the fixed stars
- planets change direction in their motion.

(a) Explain, with the aid of a diagram, how the Aristotelian model **or** the Ptolemaic model accounted for these three observations. *[4]*

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(b) Discuss the differences between the Ptolemaic model and Kepler's model of the solar system. *[3]*

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E2. This question is about the caloric theory.

(a) Describe how the caloric theory accounted for thermal conduction. *[2]*

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(b) Discuss the observations and deductions, made by Count Rumford in 1798, that disproved the caloric theory. *[3]*

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E3. This question is about theories of electric charge.

(a) A piece of plastic when rubbed with a cloth becomes electrically charged. Outline how this phenomenon is explained by the

(i) two fluid model of Du Fay. *[2]*

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(ii) modern atomic model of matter. *[3]*

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(b) In the late 19th century, J J Thomson measured the charge-to-mass ratio for an electron. Outline how this measurement was made. *[3]*

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E4. This question is about Bohr's derivation of the Rydberg constant.

Bohr derived a theoretical equation that enabled the energy E_n of the electron in the n^{th} energy level of an atom of hydrogen to be calculated. Bohr's equation is

$$E_n = -\frac{13.6}{n^2}\text{eV}.$$

(a) State the postulates made by Bohr to derive this equation. *[2]*

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(b) Rydberg discovered an empirical equation for calculating the different wavelengths in the spectral series of atomic hydrogen. Use the Bohr equation to deduce a numerical value for the Rydberg constant R_H. *[4]*

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E5. This question is about determinism.

(a) Outline how Heisenberg's uncertainty principle with regard to time-energy applies to an experiment designed to measure the energy of a moving electron at a known instant in time. *[2]*

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(b) Outline why Heisenberg's uncertainty principle means that fundamental laws cannot be deterministic. *[2]*

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Option F — Astrophysics

F1. This question is about measuring stellar distances.

(a) Describe what is meant by

(i) apparent brightness. *[1]*

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(ii) apparent magnitude. *[2]*

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(iii) absolute magnitude. *[1]*

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(b) State the property of a star that is most closely related to its absolute magnitude. *[1]*

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(c) The star Ross 128 has an apparent magnitude that is less than its absolute magnitude. Explain, with reference to this statement, why the method of stellar parallax may be used to measure the distance of Ross 128 from Earth. *[3]*

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(This question continues on the following page)

(Question F1 continued)

(d) Describe how the observed spectrum of very distant stars can be used to estimate their absolute magnitude. *[4]*

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(e) The apparent brightness of Ross 128 is $7.9\times10^{-15}\,\mathrm{W\,m^{-2}}$ and its luminosity is $1.1\times10^{21}\,\mathrm{W}$. Determine in parsecs, the distance of Ross 128 from Earth. *[3]*

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F2. This question is about the Doppler shift and the expansion of the universe.

When light from distant galaxies is analysed, the spectral lines are observed to have been Doppler shifted.

(a) State the reason for this Doppler shift. *[1]*

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(b) Penzias and Wilson discovered that there was a uniform source of microwave radiation from every direction in the universe. Explain how this discovery supports the theory that the universe is expanding. *[2]*

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(c) It is suggested that the rate of expansion of the universe might have been gradually increasing since the Big Bang. State and describe the effect, if any, that this theory would predict about the observed Doppler shift of light from distant galaxies. *[2]*

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(d) A particular line in the absorption spectrum of helium has a wavelength 468.6 nm as measured in the laboratory. The line as measured in the spectrum of a star in a distant galaxy has a wavelength of 502.1 nm. Determine the speed of the star with respect to the Earth. *[3]*

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(This question continues on the following page)

(Question F2 continued)

(e) A star in a different galaxy has a recession speed of $2.3\times10^{3}\,\text{km}\,\text{s}^{-1}$. The galaxy is 31 Mpc from Earth. Use this data to estimate

(i) a value for the Hubble constant H_0. *[2]*

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(ii) the age of the universe in seconds. *[2]*

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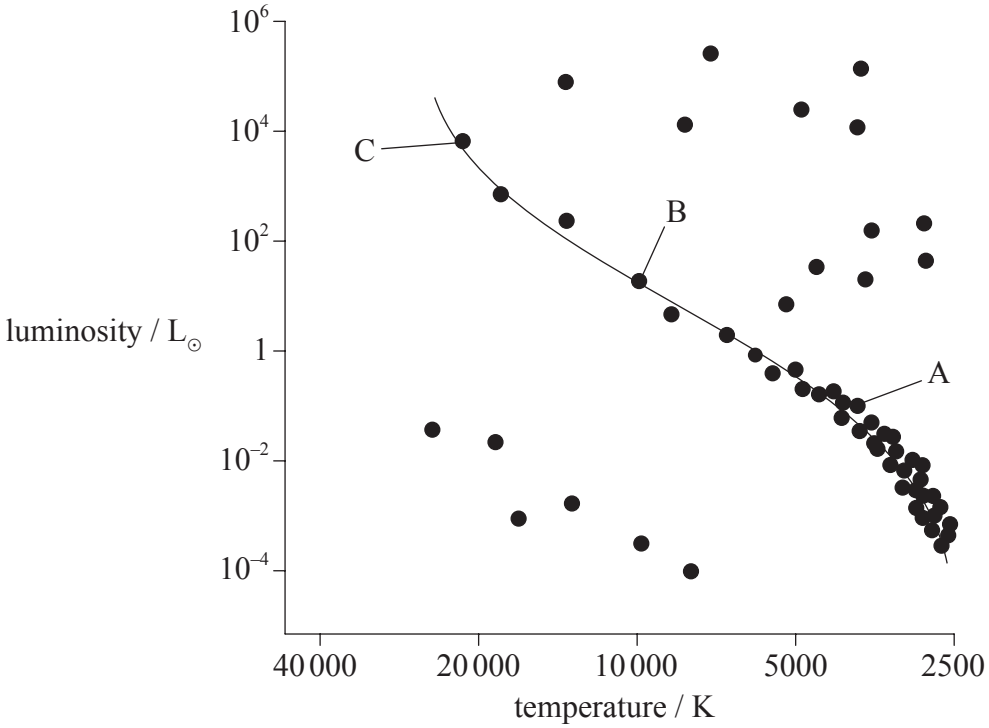
F3. This question is about stellar evolution.

The diagram below represents a Hertzsprung-Russell (HR) diagram. The three identified stars (A, B and C) are all on the main sequence.



(a) Explain which of these stars is most likely to evolve to a white dwarf star. *[2]*

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(b) Draw and label the evolutionary path of the star as it evolves to a white dwarf star. *[1]*

Option G — Relativity

G1. This question is about Special Relativity.

Two inertial observers, Alice and Bob, are moving towards each other along the same straight line with constant relative speed v. On either side of Alice are two lamps, X and Y, equal distances away from Alice and at rest in her reference frame.

The diagram below represents the situation according to Bob's reference frame.

Alice has a switch that controls each of the lamps. The lamps are initially switched off.

(a) Describe what is meant by an inertial reference frame. *[1]*

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(b) Alice closes the switch, producing an electromagnetic signal that travels from her to the lamps. When either lamp receives the electromagnetic signal it turns on. State and explain the order in which the signal arrives at the lamps (X first, Y first **or** simultaneously)

(i) according to Alice. *[2]*

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(ii) according to Bob. *[2]*

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(This question continues on the following page)

(Question G1 continued)

(c) Explain, in terms of the path taken by electromagnetic waves from the switch to Bob, why Bob receives light from lamp Y before light from lamp X. *[2]*

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(d) Two events are defined as follows:

- event P: the switch for lamp X is closed
- event Q: the light from lamp X arrives at Alice.

Alice measures a time t_A and Bob measures a time t_B between these two events.

(i) Discuss, with reference to proper time, the difference in value between t_A and t_B. *[3]*

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(ii) State and explain whether your answer to (d)(i) would be different for the situation in which Alice was moving away from Bob at speed v as measured by Bob. *[2]*

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(This question continues on the following page)

(Question G1 continued)

(e) Alice measures the distance between the lamps to be 30.0 m. The speed v is 0.90 c.

(i) Explain whether the proper length between the two lamps is greater than, equal to **or** less than 30.0 m. *[1]*

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(ii) Calculate the distance between the lamps, as measured by Bob. *[2]*

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G2. This question is about relativistic velocity addition and relativistic mass.

A particle, P, is moving at constant velocity 0.950c along the x-axis, with respect to an inertial laboratory reference frame. The diagram below represents this situation according to the laboratory reference frame.

The particle decays. One of the decay products is a smaller particle Q of rest mass 940 MeV c^{-2} that is ejected at velocity 0.900c along the x-axis relative to P's reference frame.

The diagram below represents the situation according to P's reference frame. The other decay products are not shown.

(a) Calculate the velocity of particle Q as measured in the laboratory reference frame. *[2]*

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(b) Calculate the difference between the mass of particle Q in P's reference frame and the laboratory reference frame. *[3]*

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G3. This question is about energy and momentum.

A stationary K^0 particle decays into two π^0 pions as represented by the following equation.

$$K^0 \rightarrow \pi^0 + \pi^0$$

The following data are available.

Rest mass of the $K^0 = 498\,\text{MeV}\,c^{-2}$
Rest mass of the $\pi^0 = 135\,\text{MeV}\,c^{-2}$

(a) Deduce that the momentum of each of the pions is $209\,\text{MeV}\,c^{-1}$. *[3]*

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(b) Using your answer in (a), calculate the speed of each of the pions. *[3]*

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G4. This question is about spacetime and black holes.

(a) State

(i) what is meant by spacetime. *[1]*

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(ii) the path followed by a point mass moving through spacetime. *[1]*

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(b) Use your answers to (a)(i) and (ii) to describe what is meant by a black hole. *[2]*

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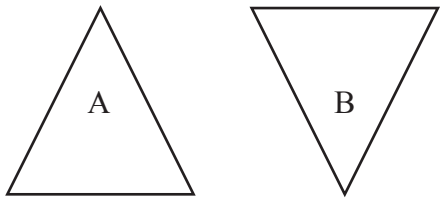
Option H — Optics

H1. This question is about dispersion.

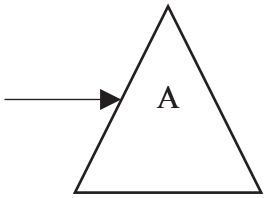
Diagram 1 below shows two identical prisms A and B. Prism B is inverted with respect to prism A.

Diagram 1



A narrow beam of white light is incident on a glass prism A as shown in diagram 2.

Diagram 2



(This question continues on the following page)

(Question H1 continued)

All the light incident on prism A passes through prism B.

(a) (i) On **diagram 2** opposite, draw lines to show the path of a ray of red light and the path of a ray of blue light as it passes through and emerges from prism A. Label the paths *R* for red and *B* for blue. *[2]*

(ii) On **diagram 2** opposite, draw prism B in the path of the light that has passed through prism A. Draw lines, continuing from those from (a), to show the path of the ray of red light and the path of the ray of blue light as they pass through and emerge from prism B. *[2]*

(b) A screen is placed in the path of the light emerging from prism B. Describe the appearance of the light on the screen. *[2]*

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H2. This question is about the reflection and refraction of laser light.

(a) Define *refractive index*. *[1]*

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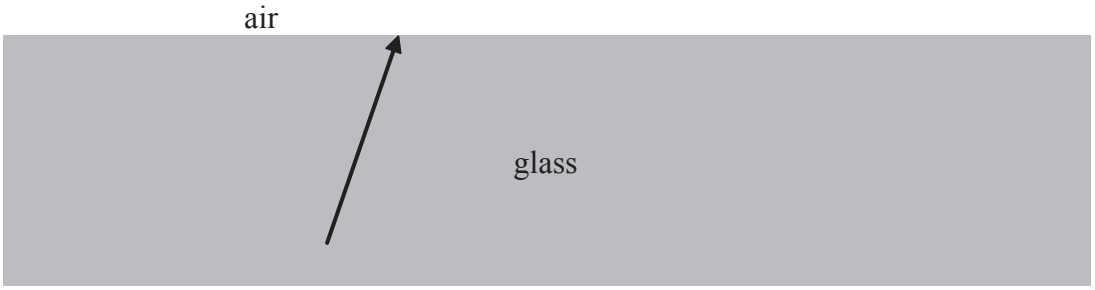
(b) A beam of laser light is incident on a glass/air boundary.



(i) On the diagram above, draw rays to show the reflected ray (label this L) and the refracted ray (label this R). *[1]*

(ii) The angle of incidence of the beam is gradually increased. Deduce how the path of the laser light would change for angles of incidence up to 80°. The refractive index of the glass is 1.5. *[4]*

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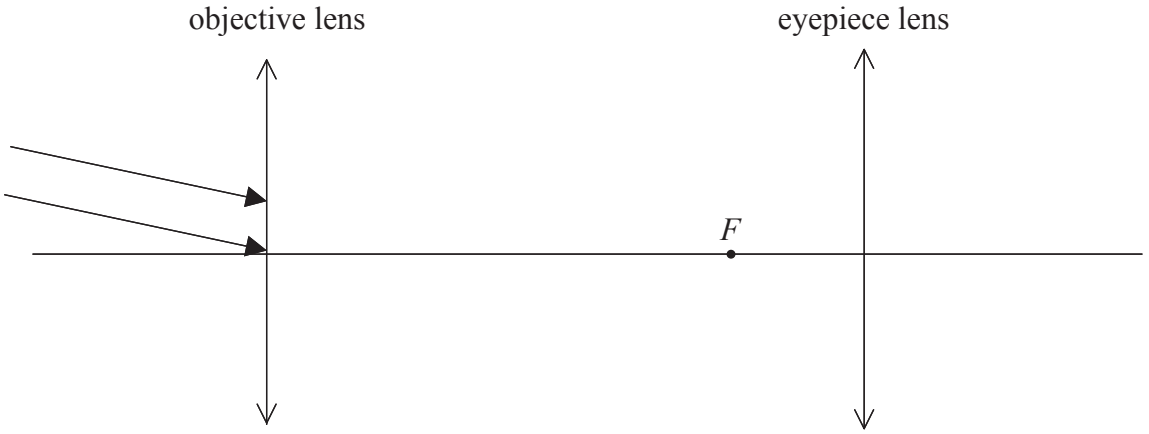
(Option H continued)

H3. The following question is about an astronomical telescope.

A telescope in normal adjustment is pointed at a distant object. Parallel light rays are incident on the objective lens, as shown in the diagram below.



The lenses are positioned so that their focal points are at the same location, labelled *F* on the diagram.

(a) (i) On the diagram above, construct a ray diagram to locate the final image. *[3]*

(ii) On the diagram above, label with the letter E where the eye should be placed in order to view the image. *[1]*

(iii) State, with a brief explanation, the location of the final image. *[1]*

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(Question H3 continued)

(b) Use your diagram to explain why the image produced by a telescope is

(i) magnified. *[2]*

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(ii) inverted. *[1]*

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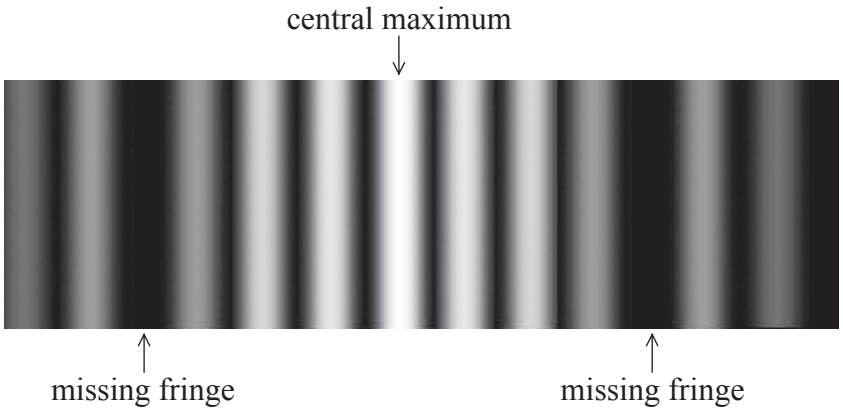
H4. This question is about double slit and multiple slit diffraction.

In a Young's double slit type experiment, laser light of wavelength 650 nm is shone onto two slits. The resulting fringe pattern on a screen placed beyond the slits is shown below. The separation of the slits is 1.4×10^{-4} m.



(a) (i) Explain the reason for the missing fringes. *[2]*

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(ii) Calculate the width of each slit. *[2]*

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(b) The double slit is replaced with a very large number of slits. Each of the slits is of a smaller width than those of the double slit but their separation is the same as in (a). Describe and explain any changes in the appearance of the fringe pattern as shown in (a). *[3]*

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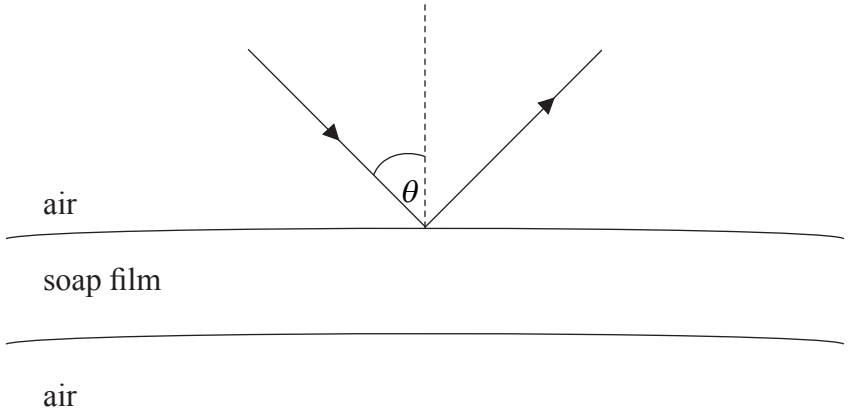
H5. This question is about thin film interference.

The diagram below shows one ray of light of wavelength λ that is reflected from the top surface of a soap film.



Constructive interference takes place for light of wavelength λ at the angle θ.

(a) On the diagram above, draw the path followed by the ray after it enters the soap film. *[1]*

(b) On the diagram above, identify with the letter "X" any points where there is a π-phase change. Explain your choice. *[2]*

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